Cooperative Research and Development for Advanced Microturbine System

United Technologies Research Center
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Agenda

Project goal and approach

- Original plan shared at 2002 Peer Review
- Re-focused plan after UTC/CTC Strategic Alliance Agreement

Accomplishments Since 2002 Peer Review

- Demonstrated 5-pt efficiency increase potential for microturbine/ORC system
- Produced manufacturing trials of ceramic, integral vane ring
- Finalized design of premixing combustor

Next Steps

- Integrate C200/ORC system and demonstrate 40% electrical efficiency

Conclusions

- UTC Power is launching PureCycle™ 200

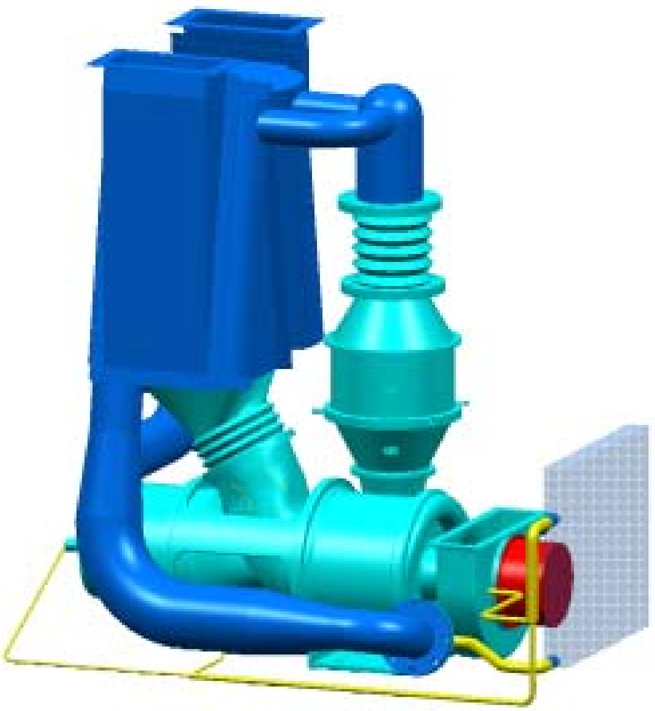
Goal and Approach Shared at 2002 Peer Review

DOE Advanced Microturbine System Goals

- Electrical efficiency = 40%
- NOx = 7 PPM on natural gas fuel
- Multi-fuel capability
- 11,000 hour between major overhaul
- System cost = $500US/kW

UTRC Goal and Approach

- Affordably increase PWC ST5-powered ENT400 microturbine from 30% to 40% electrical efficiency with NOx < 7 ppm



Re-Focused Goal and Approach

DOE Advanced Microturbine System Goals

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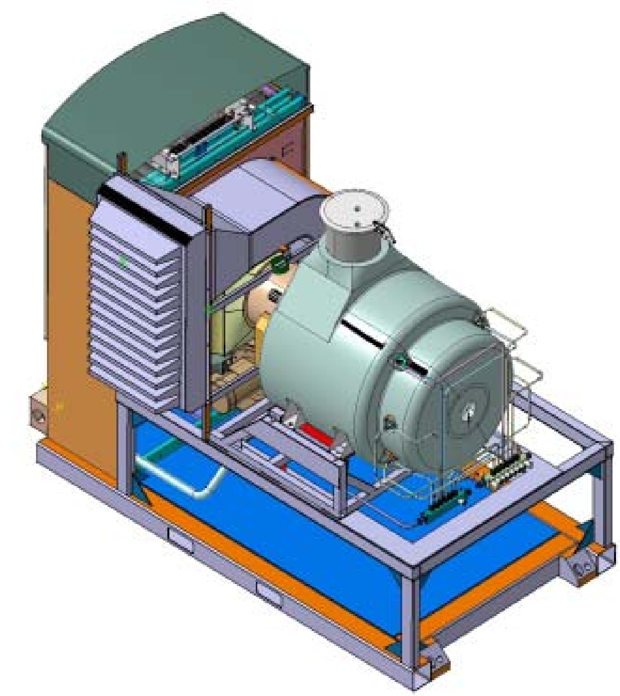


UTRC Goal and Approach

- Affordably increase Capstone C200 microturbine from 33% to 40% electrical efficiency with NOx < 7 ppm

UTC/CTC Strategic Alliance

The October, 28, 2002 news release contained the following:

“The strategic alliance between UTC and Capstone is a long term agreement to integrate, sell, and service microturbine-based **combined heat and power solutions** for commercial buildings.”

“UTC and Capstone intend to **build on key product, technology, and channel strengths** of the companies, including those of UTC’s Carrier Corporation – the leading manufacturer of heating, ventilation, and air conditioning systems.”

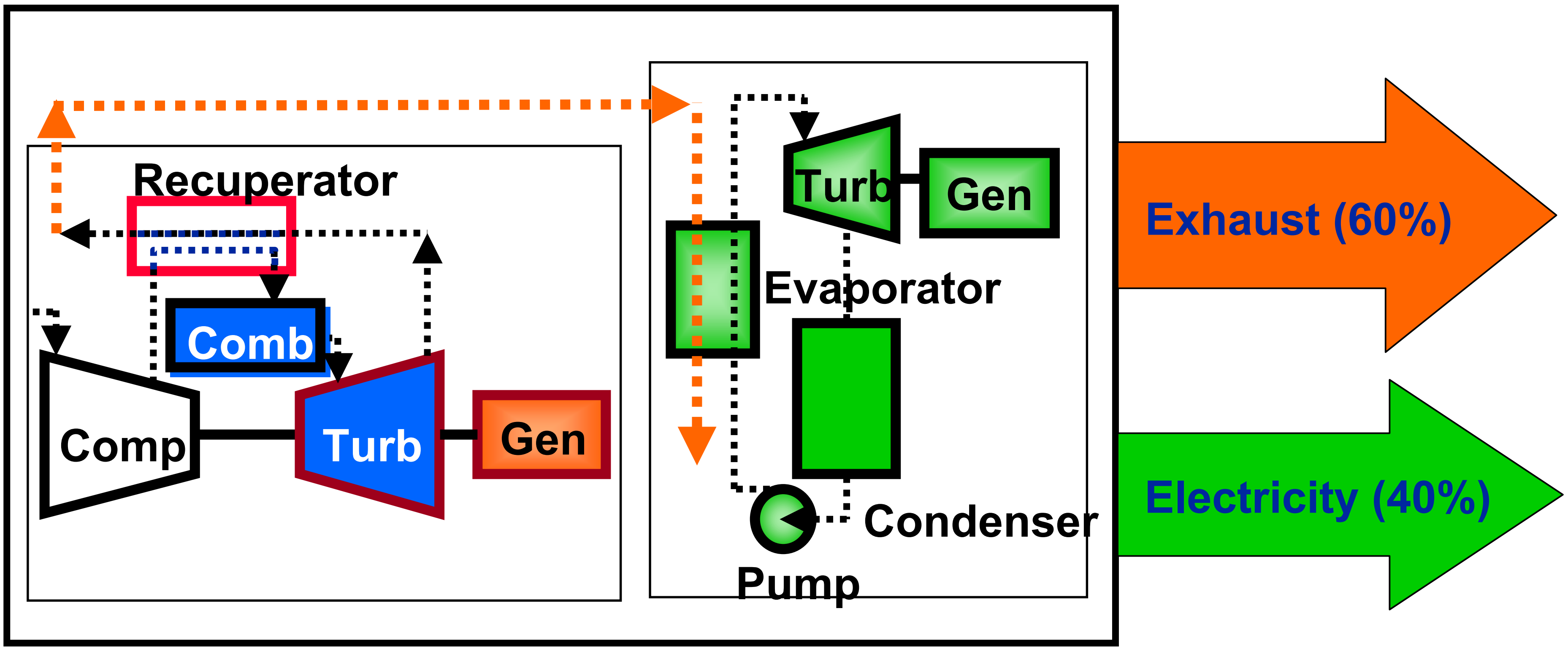
“The agreement covers North America and most of Europe.”

“As part of the alliance agreement, UTC has committed to purchase a 4.9 percent stake in Capstone.”

Consistent Approach to AMS

UTRC sustains recycling exhaust energy into power as the affordable means to high efficiency

- C200 starting point does not now require UTRC planned engine technology to achieve AMS goals.
  - Ceramic turbine vane and blade for higher TIT
  - Lower emission combustor



UTRC AMS Tasks and Accomplishments

Task 1 Preliminary Design (Oct 2000 – Dec 2001)

- System identification for AMS goals (Mar 2001)
- Preliminary Design of ORC (Mar 2001), combustor (Aug 2001), and ceramic turbine (Nov 2001)

Task 2 Subsystem Technology Development (Apr 2001 - Jun 2003)

- Demonstrated 80 kW from ORC prototype (Feb 2002)
- Completed design and produced manufacturing trials of ceramic, integral blade ring (Feb 2003) – further development suspended
- Completed design and manufactured low emission combustor for wide turndown (Nov 2002) – further development suspended

Task 3 & 4 System Integration/Demonstration (Feb 2002 – Apr 04)

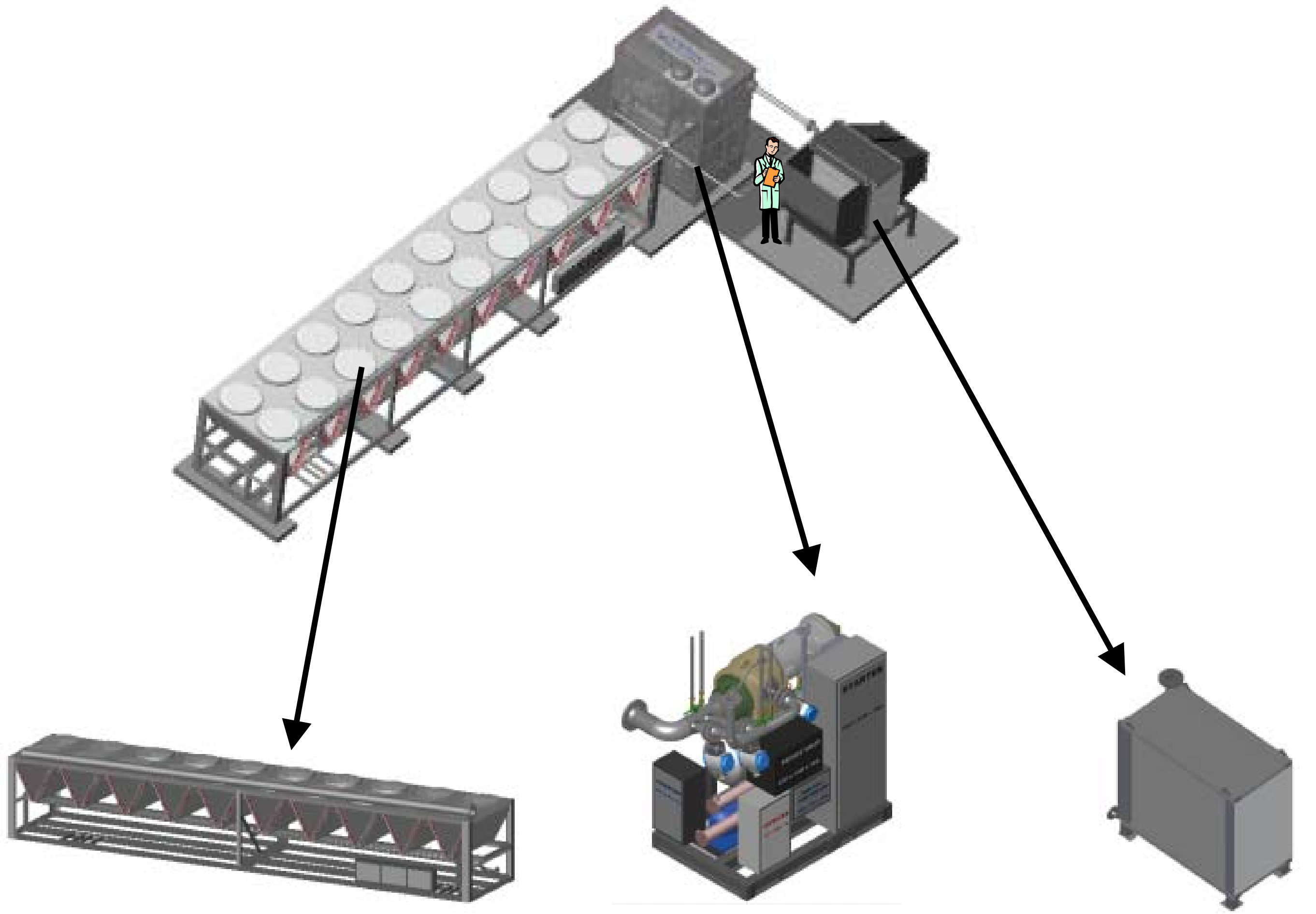
- Demonstrated 5-pt efficiency increase potential for microturbine/ORC system (Oct 2002)
- Integrate C200/ORC system and demonstrate 40% electrical efficiency (Sep 2004)

Task 5 Field Trial Durability Demonstration (Jan 05 – Sep 05)

- Suspended

ORC System Consists of 3 HVAC Modules

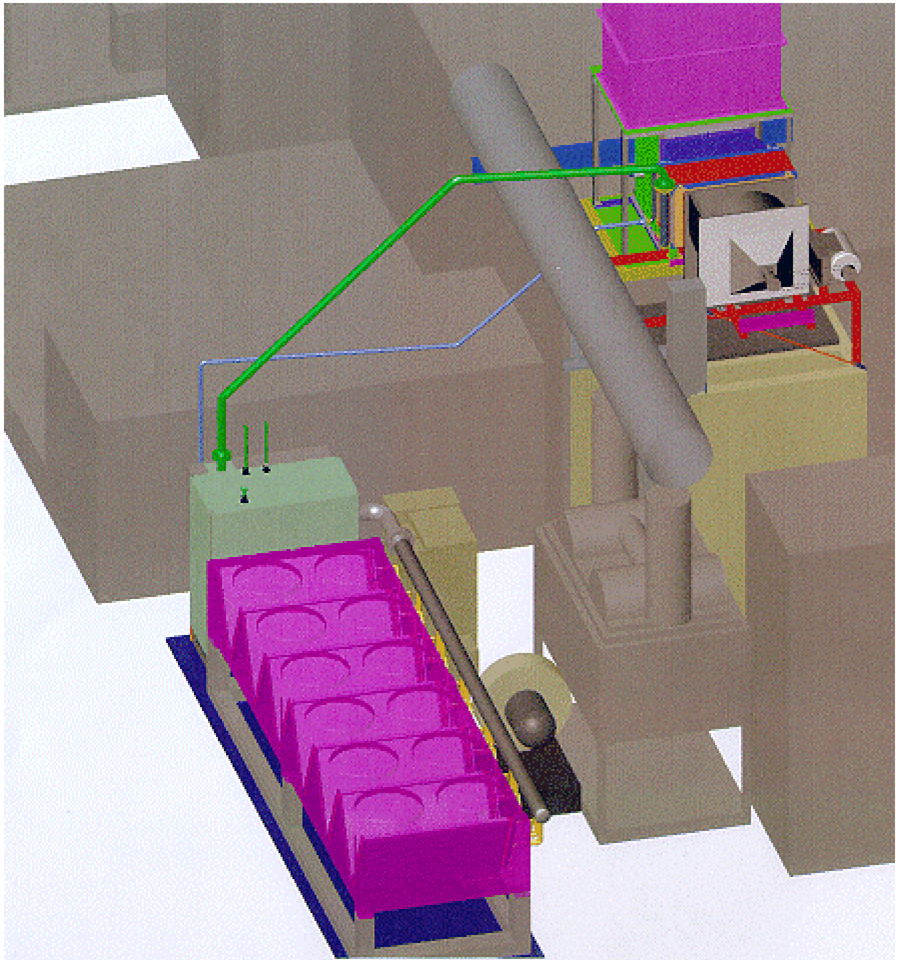
HVAC leverage limits cost



100 kW ORC Engineering Prototype Driven by 1.5MW IGT

Integrated to portion of IGT exhaust

- Delivered 100kW of electrical power to UTRC grid
- Demonstrated cavitation-free operation
- Validated transient control strategy



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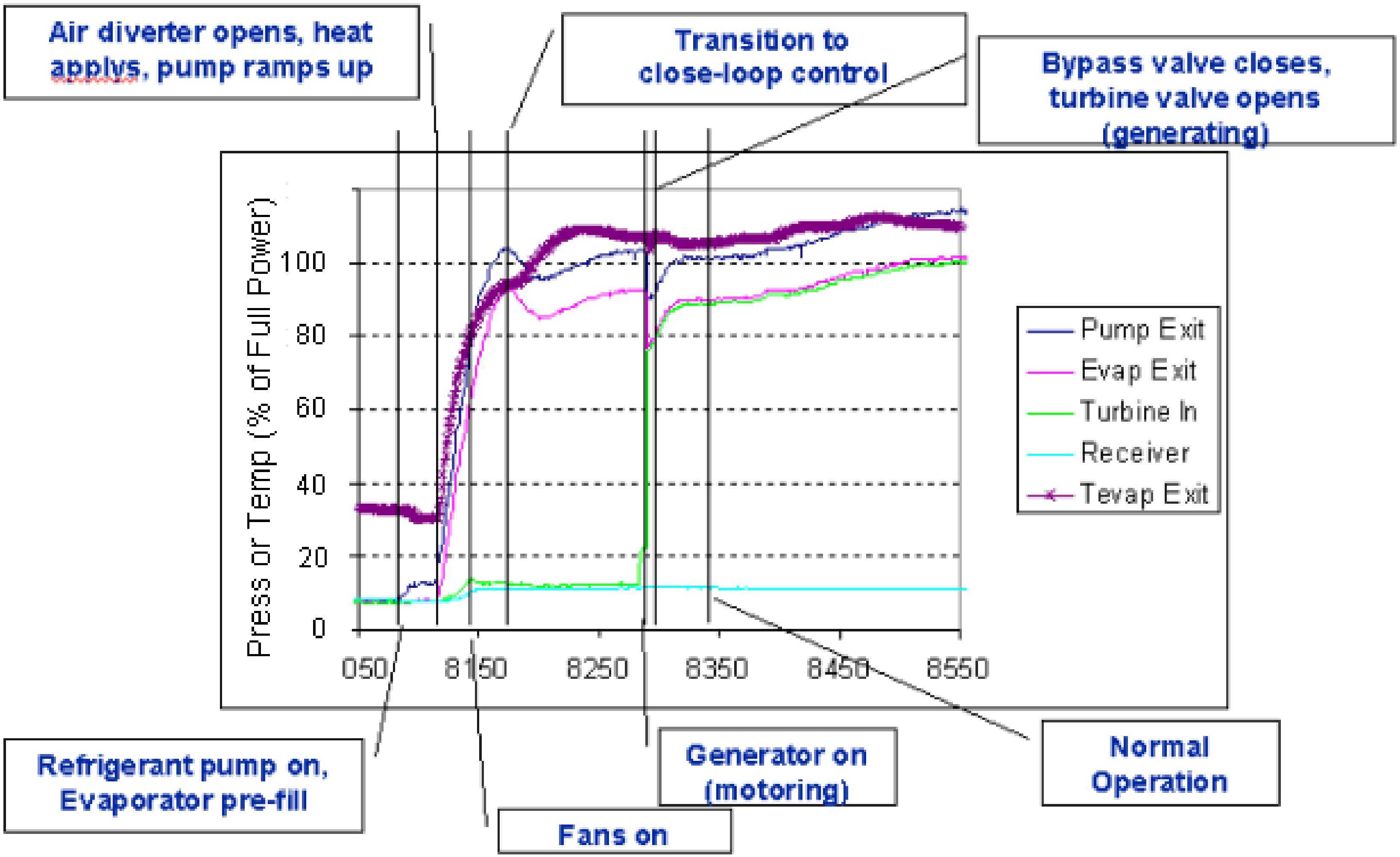
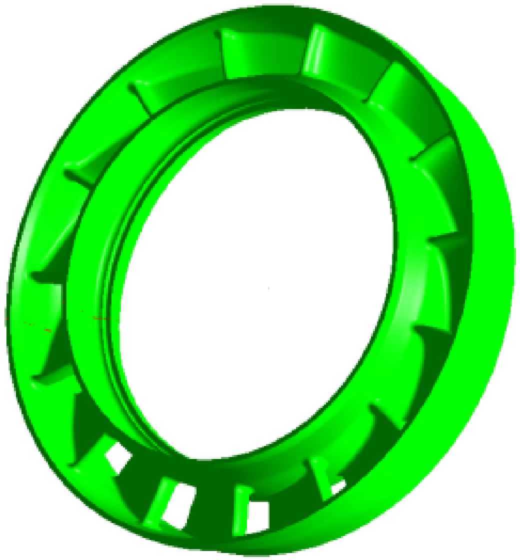
Start-Up Validated with ORC Engineering Prototype



Ceramic Turbine Components to Enable Higher Performance

Si_3N_4 IBR
Saint Gobain (NT154)



Integral Si_3N_4 Vanes
Kyocera (SN282)

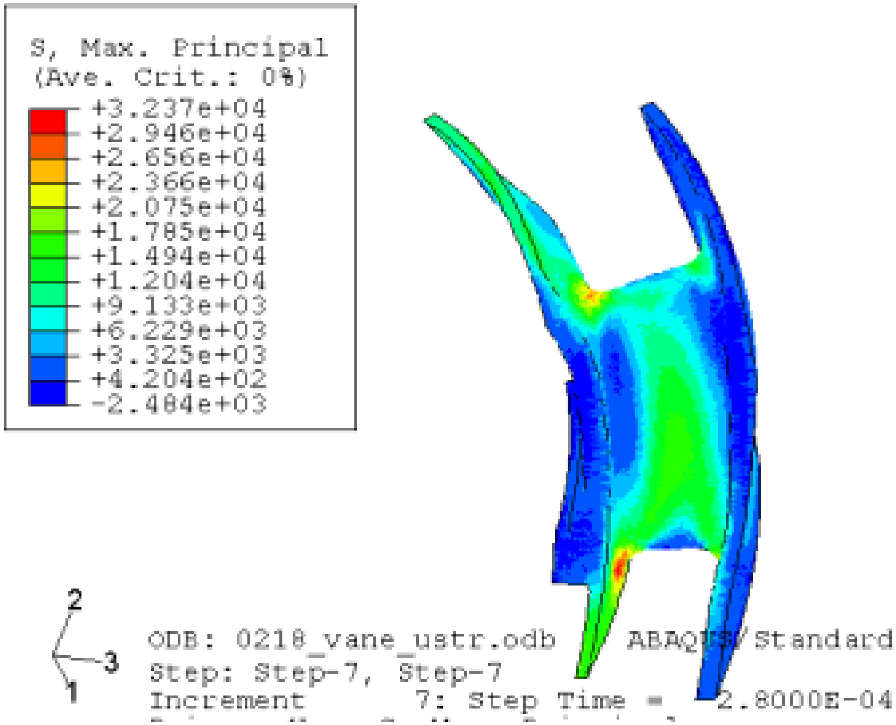
Government Lab Companion Programs

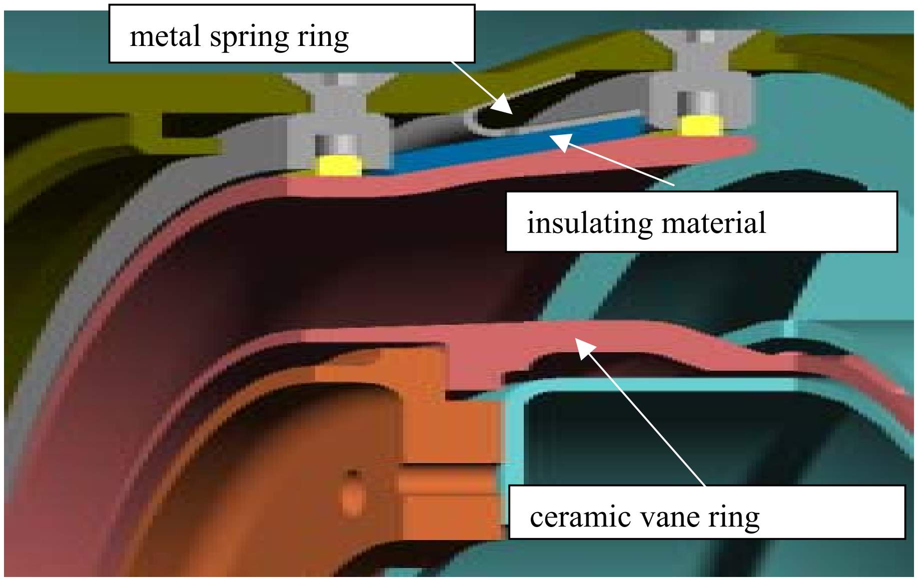
- ORNL – HTML: Characterizing silicon nitride materials, both with and without EBC
- NASA UEET: Developing high temperature EBC for CMC
- Navy/DOE: Developing EBC for silicon nitride
- US Army: Design/fab/test ceramic turbine components

Full Life Integral Vane Ring

Silicon nitride integral vane ring

- Integral ring feasible with careful attention to mounting and fillet radii to minimize transient stresses
- Maximum temperature ~2200F @ steady state
- Maximum tensile stress ~32ksi (220MPa) in transient



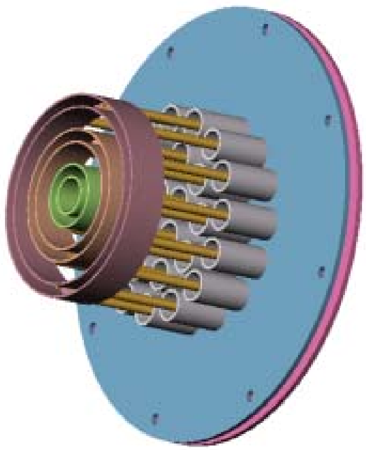


Ceramic Vane Ring Manufacturing Trials

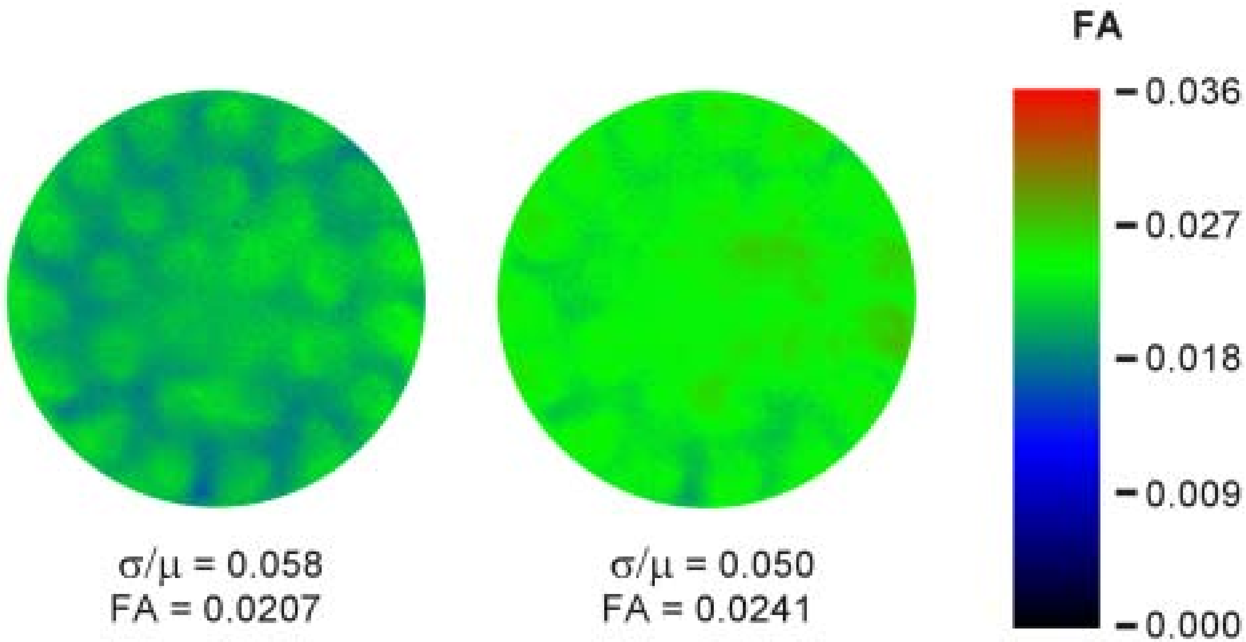
- Vane ring design for ST5+ engine configuration provided to Kyocera for manufacturing trials
- Three manufacturing-trial samples were produced by Kyocera from SN282 silicon nitride using bisque machining and sintering methods
- Good tolerance control and yield for initial manufacturing trial
- Two of the samples are candidates for gas generator evaluation under companion collaborations

~9 inch OD SN282 vane rings

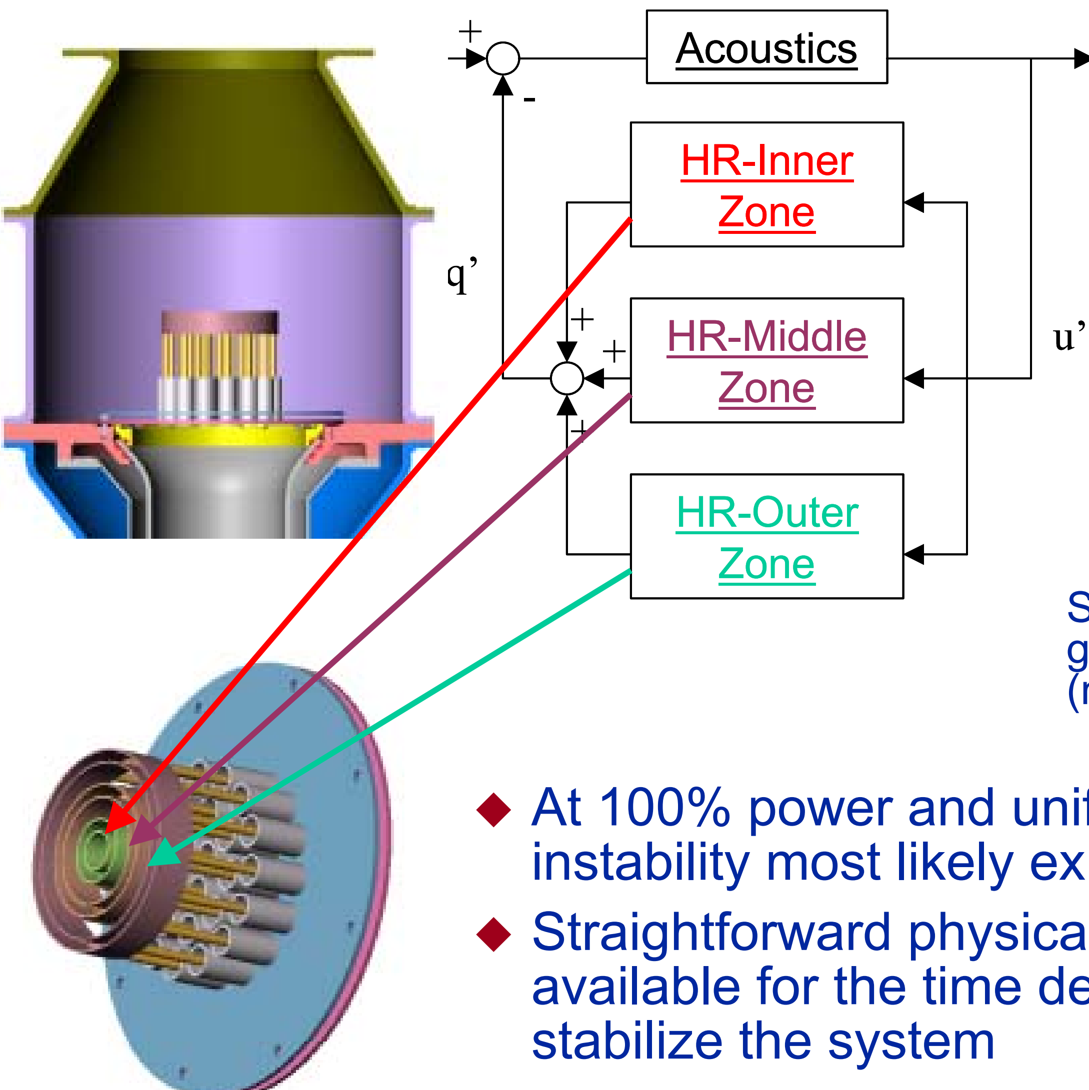
High Fuel-Air Uniformity is Key to Low NOx

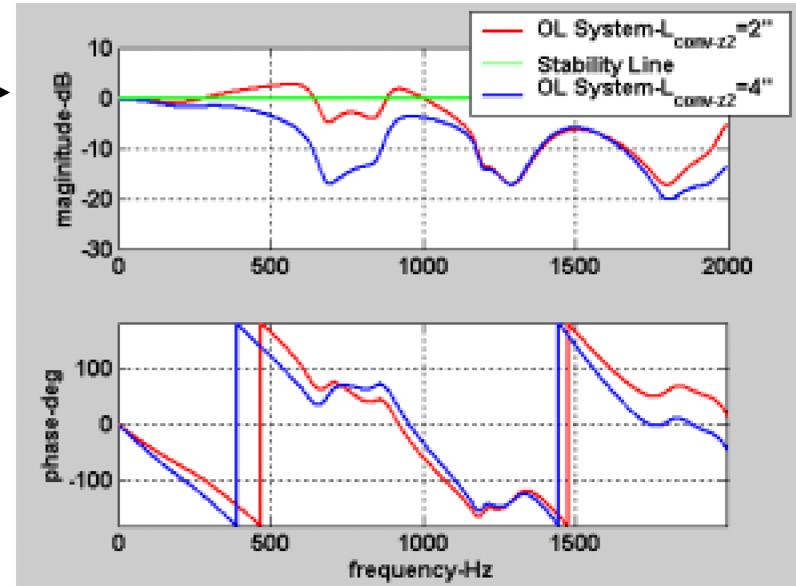


Uniform Mixing (< 6 %) Achieved



Thermoacoustic Model Used to Avoid Instabilities





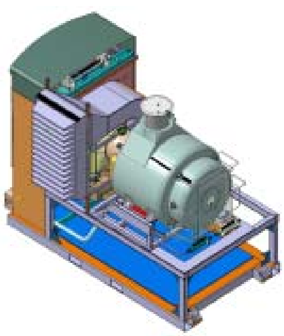
Stability Criteria: Unstable when open loop gain above 0 dB and phase at 180°. (negative feedback)

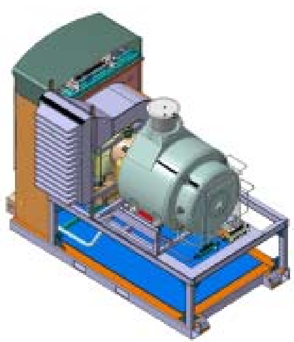
- At 100% power and uniform fueling of each zone, system instability most likely exists near 480 Hz
- Straightforward physical alterations (longer injectors) are available for the time delay adjustment if needed to stabilize the system

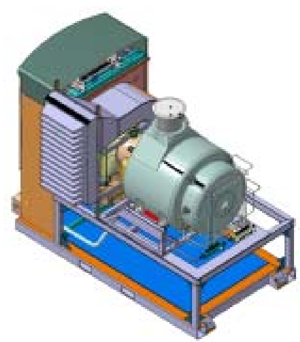
FY04 Next Steps

Integrate C200/ORC system and demonstrate 40% electrical efficiency (Sep 2004)

- Add HW heat exchanger to produce thermal output
- Substitute water-cooled condenser
- Mechanical and control integration with C200
- Test integrated system at steady state and transient conditions







$$
\begin{aligned}
\text{System Efficiency} &= (P_{C200} + P_{ORC})/E_{fuel} \\
&= Eff_{C200} \times (P_{C200} + P_{ORC})/\ P_{C200} \\
&= 33\% \times (600 + 128)/600 \\
&= 40\%
\end{aligned}
$$

UTC Team is on Pathway for AMS 40% Efficiency Goal

Re-focused plan has transitioned to CTC C200 basis to achieve AMS goal

- Combines leading edge technology of CTC and UTC
- Sustains approach to affordably recycle waste into power
  - ORC thermal output enhances its value
- Ceramic turbine technology investments benefiting other collaborations

Together, UTC products and plans have great public benefit

- Expand customer choice for reliable, affordable electrical and thermal energy
- Delivers the energy streams with less fuel consumption and pollutants
- UTC/DOE collaboration is having a direct impact on the marketplace by enabling new products

Waste Heat is Everywhere

Gas Compression

Landfill Flare

Landfill Engine

Industrial Processes

Annual U.S. industrial waste > 4 quadrillion BTU (160 GW)

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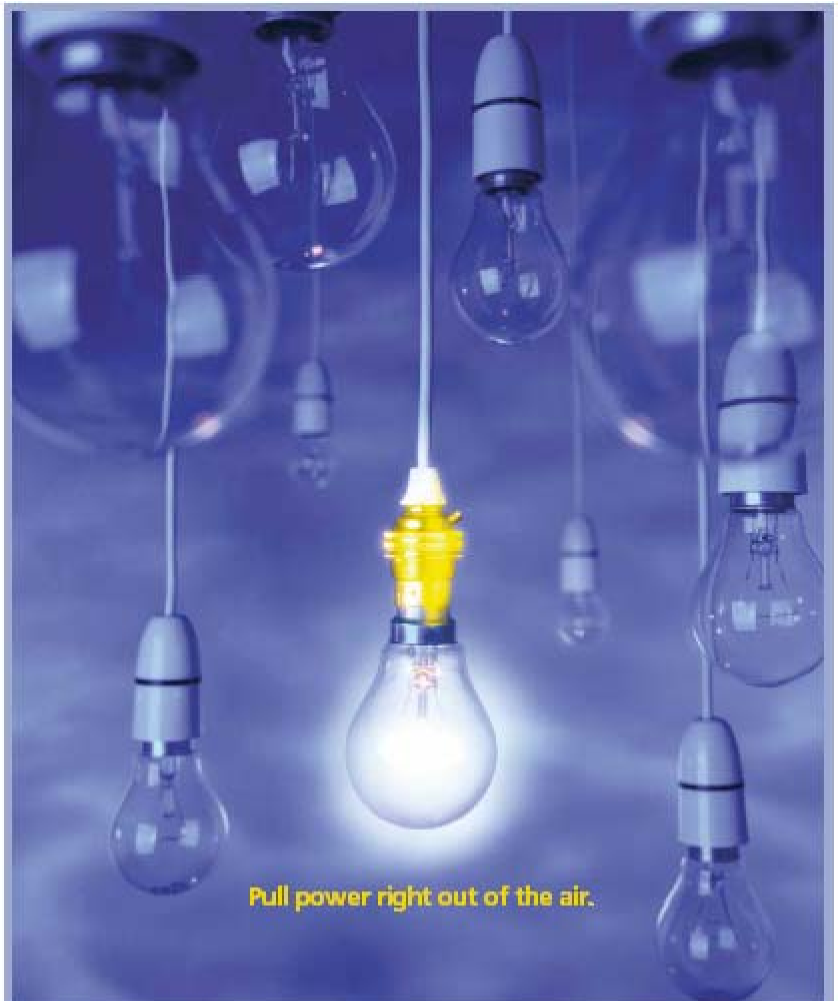
UTC Power PureCycle™ 200



UTC Power
A United Technologies Company

Turn Waste Heat into Electricity – with the PureCycle™ Zero Emission Power System.

The clean way to profit from waste heat.
If you're generating heat, you can create electricity. And maybe you already are. But even if you have a waste heat-to-energy system in place, you're not using your resources to their fullest potential. Because now you can use the PureCycle™ power system, a unique heat-to-electricity solution from UTC Power.

The PureCycle™ power system is a closed-cycle process that uses waste heat to generate electrical power. Driven by a simple evaporation process, the entire system is enclosed, which means it produces no emissions. The only product is electricity. And the fuel – waste heat – is free, so there's no cost to power the system once it's installed.

Flexible, site-compatible design.
The PureCycle™ system can be used with any waste heat above 500°F (gaseous) or 200°F (liquid or vapor), whether it comes from engines, flares or industrial sources. The PureCycle™ power system is also surprisingly compact which makes the system moveable. If, for whatever reason, you wish to use another heat source, the system can be disengaged and relocated.

Built and supported by energy experts.
While the PureCycle™ power system is relatively new, it draws upon decades of United Technologies Corporation innovation

PureCycle™ Power System features:

- **Waste-heat powered** – The PureCycle™ power system is designed to be used with engines, turbines, industrial processes or flare waste heat. In each case, you're leveraging current resources, and the fuel is free.
- **No system emissions** – In some cases the PureCycle™ power system can qualify for emissions credits and help lower net emission/kWh of the host site.
- **Safe working fluid** – Your operations and the environment are protected through the use of a non-flammable, non-ozone-depleting working fluid which is sealed within the system.
- **Low generation cost** – Generation costs of the PureCycle™ power system are lower than natural gas fueled reciprocating engines. In addition, the system is easily installed in many cases, resulting in attractive payback periods.
- **Fully automated, self contained** – PureCycle™ power systems are designed to run unmanned – 24/7/365. And because the systems are sealed, they're inherently weather-resistant, so there's no need for protective housing.
- **Low operating cost** –

~~Fuel~~ ~~NOx~~